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Sustainability **2009**, *1*, 1042-1068; doi:10.3390/su1041042

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Sustainability in Agricultural Mechanization: Assessment of a Combined Photovoltaic and Electric Multipurpose System for Farmers

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Received: 9 September 2009 / Accepted: 6 November 2009 / Published: 17 November 2009

Abstract: This study is dedicated to the assessment of the possibility of replacing fossil fuels with renewable energy as a source of power in modern agriculture. We examined the use of a completely sustainable agricultural mechanization system based on a renewable energy system and a battery powered, multi-purpose agricultural vehicle. This assessment is based on the RAMseS project, financed by the European Commission under the 6th Framework Program, which has led to the actual manufacturing of the system, at present being tested in Lebanon. In the present study, we assess the environmental and economic performance of the RAMseS system. We evaluate the external costs by means of a specific model that takes into account the life-cycle cost (LCC), economical indexes, and life-cycle emissions for the vehicle during its life span. The results are compared with those of a standard vehicle based on the internal combustion engine (ICEV). The results show that the RAMseS system can avoid the emission of about 23 ton of CO_{2equ} per year. The life cycle cost (LCC) assessment using MATLAB software shows that the LCC for the RAMseS vehicle and the ICEV are the same for a fuel unit price (pf) of 1.45 €/L. Finally, we show that almost 52 % of the RAMseS LCC is due to the batteries of the electric vehicle. A 50% decrease in batteries unit cost would cause the LCC of two system to be the same at a fuel cost of 0.8 €/L. The final result is that the RAMseS system remains—at present—

marginally more expensive than an equivalent system based on conventional fuels and internal combustion engines. Nevertheless, with the gradual depletion of fossil fuels, all electric agricultural mechanized system provide an alternative solution that is dependent only on renewable energy and recyclable resources.

Keywords: pollution; environment; agriculture; sustainability; electric vehicles; renewable energies; life-cycle cost

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Nomenclature

4WD	4 Wheel-Drive
ASABE	American Society of Agricultural and Biological Engineers
BOS	Balance Of System
AF	Annuities Factor
C_{BOS}	Cost of BOS (% of C_{PV})
C_{EV}	EV cost without battery (€)
C_{EVB}	Cost of EV battery (€/kWh)
C_{fuel}	Cost of fuel (€)
C_{ICEV}	Custom cost of ICEV (€)
C_L	Land cost (€)
$C_{N\text{-}REC}$	Non-recurring costs of ICEV (€)
$C_{O\&M0}$	Operation and maintenance cost for first year (€)
$C_{O\&M}$	Operation and maintenance cost (€)
C_{PCU}	Cost of PCU (€/kWp)
C_{PV}	Custom cost of PV (€/W_p)
C_R	Replacement costs of RAMseS (€)
C_{REC}	Recurring costs of ICEV (€)
C_{SB}	Stationary battery cost (€/kWh)
C_{TSI}	Cost of Tax-Shelter-Insurance (€)
C_{yfuel}	Yearly cost of fuel (€)
DF	Deterioration factor
d	Discount rate (%)
E	Conversion efficiency of PV
EF_{adj}	Final emission after account for transient and deterioration (g/hp-hr)
EF_{ss}	Zero-hour, steady-state emission factor (g/hp-hr)
EV	Electric Vehicle
EVB	Electric Vehicle Battery
E_{year}	Yearly collected energy by PV project (kWh)
G	Generation of electricity in life-cycle (kWh)
GHG	Green house gas

I	Solar irradiation (W/m^2)
i	Inflation rate (%)
ICE	Internal combustion engine
ICEV	Internal Combustion Engine Vehicle
i_e	Inflation rate of energy (%)
i_f	Inflation rate of fuel (%)
LCA	Life-Cycle Assessment
LCC	Life-Cycle Cost (€)
LCE	Levelized Cost of Energy (€/kWh)
L_{EV}	EV life (year)
L_{EVB}	EV battery life (year)
L_{ICEV}	ICEV life (year)
L_{PCU}	Life of PCU (year)
L_{SB}	Stationary battery life (year)
m	PV O&M cost ratio (% of C_{PV})
m-Si	Mono crystalline silicon
N	PV life (year)
N_{EVBR}	Number of replacements of EV batteries
N_{EVR}	Number of replacements of EV
N_{PCUR}	Number of replacements of PCU
NPV	Net Present Value (€)
N_{RICEV}	Replacing number of the ICEV
N_{SBR}	Number of replacements of stationary batteries
PBP	Pay Back Period (year)
PCU	Power Conditioning Unit
P_E	Energy sale price (€/kWh)
P_f	Fuel unit price (€/L)
PM	Particulate matter
PR	Performance Ratio
PV	Photovoltaic
RAMseS	Renewable energy Agriculture Multipurpose System for farmers
SB	Stationary Battery
S_{EV}	EV salvage cost (% of C_{PV})
S_{ICEV}	ICEV salvage cost (% of C_{ICEV})
soxcnv	Grams PM sulfur per grams sulfur in fuel consumed
soxbas	Default certification fuel sulfur weight percent
soxdsl	Episodic fuel sulfur weight percent
$S_{PM\ adj}$	PM emission factor adjustment to account fuel sulfur content (g/hp-hr)
STC	Standard Test Condition (1000W/m^2 irradiation, 25°C cell temperature, air mass 1.5)
TAF	Transient Adjustment Factor
TSI	Tax-Shelter-Insurance (% of C_V)

U_{EVB}	Unit cost of electric vehicle battery (€/kWh)
U_{PCU}	Unit cost of PCU (€/kWp) ,
U_{PV}	Unit cost of PV panels (€/W_p)
U_{SB}	Unit cost of stationary battery (€/kWh)
WTW	Well to Wheel

1. Introduction

The gradual depletion of the world's fossil fuel reserves, as well as the emission of pollutants, greenhouse gases, and the related climatic change, implies that the concept of sustainability cannot be neglected any longer [1]. This concept is the more relevant in agriculture, where the use (and the overuse) of fossil fuels has led to radical transformations. An activity that was, once, a paradigm of sustainability, has become something that cannot be done without the continuing support of non-renewable energy and materials. In addition, agriculture has become a major source of pollutants in the atmosphere [2].

Since agriculture is fundamental to the human existence, we have focused our efforts on addressing at least one point in terms of agricultural sustainability: that of mechanization. Mechanized agriculture has been a great bonus for humankind, freeing innumerable people from the toil of hard work in the fields. However, this freedom has been obtained at the expense of a non renewable resource: fuels obtained from crude oil. Is it possible to keep mechanized agriculture in a world of dwindling fossil supplies? This is the question that we try to answer here.

Our examination of the situation led to focus on technologies which are at the same time available and not expensive. We considered photovoltaic (PV) energy which is one of the best choices, especially for high insolation countries. In order to transform solar energy into mechanical energy, an electric vehicle (EV) provides a practical technology, better than more complex and expensive alternatives, such as hydrogen (see, e.g., Granovskii *et al.* [3]).

So far the diffusion of photovoltaic energy has been slowed down by the cost of PV systems in comparison to conventional systems. The situation is gradually changing and several studies prove the long term profitability of PV systems [4]. However, the cost effectiveness of a PV system depends on several factors, such as equipments cost, final uses, remoteness and connection to the power grid and—in view of a comparison—fossil fuel cost. El-Kordy *et al.* [5] show that even when external costs are considered, the capital cost of PV needs to be reduced by about 60% in order to be economically competitive with wind and natural gas. Wies *et al.* [6] analyzed the economic and environmental impacts of a hybrid system for remote villages. They found that the integration of a PV array into a diesel-battery stand-alone hybrid system reduces the operating costs and the airborne emissions. Similar considerations hold for electric vehicles, as analyzed, for instance, by Funk *et al.* [7], who concluded that EV hold an advantage over conventional vehicles in terms of environmental impact when the electricity that powers the vehicle is produced by low pollution, renewable sources.

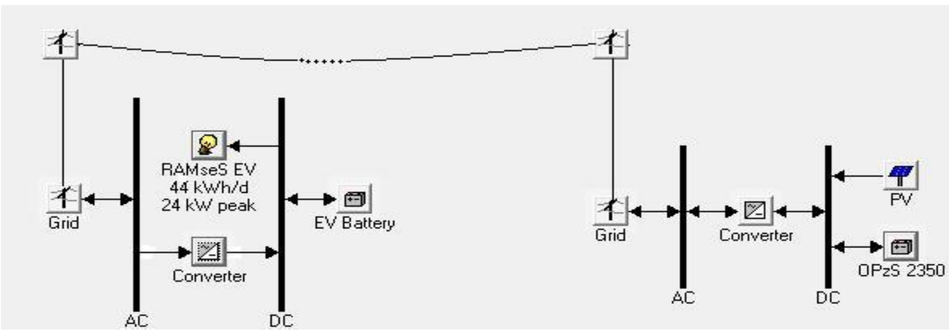
On the basis of the known data, it is possible to suggest that, already at the present stage, a combination of PV power and electric vehicles can be a convenient choice for an agricultural system destined to generate fossil-free mechanical power. This convenience is especially evident when the area where the system is operated is a high insolation country, such as a Southern Mediterranean one. Out of these considerations, the RAMseS project (www.ramses.org; the acronym ―RAMSES” stands for ―Renewable Energy Agricultural System for Farmers” but we prefer to read it with the ancient Egyptian meaning of ―Born of the Sun-God, Ra”) was born under the auspices of the European Commission under the 6th Framework Program. A constraint to this specific project is that, in the country of installation of the system (Lebanon), current legislation does not allow private users to sell electric energy to the national grid. For this reason, the PV/electric vehicle was equipped also with a set of stationary batteries that store the energy obtained from the solar photovoltaic panels.

In July 2008, the complete RAMseS system was installed at its final destination, in Lebanon, in the monastery of Saints Sarkis and Bakhos in Ashkout, where it is at present undergoing practical testing. The whole system is rugged and requires little maintenance. It uses only renewable energy and most materials of the system can be efficiently recycled. The purpose of the present paper is to evaluate the RAMseS system in these terms. We show that the system does provide a considerable environmental benefit, although its costs are still slightly higher than those of an equivalent system based on fossil fuels and internal combustion engines.

2. Materials and Methods

The RAMseS system is a multi-purpose, integrated energy system for a series of services, which include energy storage, power production on demand, and back-up power system against grid blackouts. The RAMseS electric vehicle can be used for a variety of purposes such as crops transportation, spraying of pesticides, irrigation, crop collection and as a low speed road vehicle. One innovative element of such system is the dual use of batteries, which not only provide energy storage, but also power for the vehicle (Figure 1).

Figure 1. Schematic diagram of the RAMseS system.



The RAMseS PV panels have been installed in a site in the Monastery of Saints Sarkis and Bakhos in Ashkout, in Lebanon. According to the available data [8], the yearly average horizontal radiation in the region is 4.8 kWh/m²·day. The RAMseS project uses two sets of batteries, one on-board and another stationary. The EV's batteries consist of two stacks of eight batteries. The stationary batteries consist of 23 lead acid single cell battery modules connected in series. These batteries have a long service life, being able to operate under float charging for up to 20 years [9], so these batteries need to be replaced only once (that is after 15 years) during the lifetime of the system, considered here as of 30 years.

These and other elements of the RAMSES system are described in Table 1. In the table, the performance ratio (PR) is estimated considering a 25% energy loss due to power conversion unit (PCU) inefficiency [11]. This estimation may appear pessimistic, but it includes such factors as inverter, battery charger, cabling, rectifier and others. Finally, we consider that each stack consists of 8 batteries, so to consume 44 kWh/day, seven stacks are needed (considering 75% DOD).

Table 1. RAMseS PV panels and battery specifications.

Batteries	On-board EV battery	Stationary battery
Type	Lead-gel dryfit	Lead-acid
Stack Volt	48	45
Stack AH	180@ C(5)	1,910 @ C(24)
Number in stack	56 (8 × 7)	23
Cycle	700 @ 75 % DOD	-
Life-cycle replacement	14	1
Panels	Cell efficiency (at STC)	17%
	Total panels area (A)	72 m^2
	PR (fulfillment, Mismatch,	0.75
	Life-time (N)	30 yr
	Panels installation region	Lebanon
	Yearly average irradiation (I)	1,752 $kWh/m^2/yr$

The most important parameters for the assessment of PV systems include: conversion efficiency (*E*), solar irradiation (*I*), performance ratio (PR), and life-time (*N*). Usually the analysis period is chosen as the service life of the longest-living component. In the case of PV comparison, the PV useful life is chosen as equal to the life-cycle period of the whole system that is 30 years. The total life-cycle electricity generation (*G*) by the PV system is calculated as:

$$G = E \times I \times PR \times N \times A = 482500 \text{ kWh}$$

As a consequence, the average energy production of the RAMSES system is about 44 kWh/day. Since we can consider that electric motors convert 75% of the chemical energy from the batteries to power the wheels [10], the daily net consumed energy must be reduced to 33 kWh/day. This is the daily net energy that the EV converts to work.

The RAMseS EV's main electric DC motor has a power of 12 kW. The vehicle also has an auxiliary on-board 12 kW motor. It uses a standard power take off (PTO) shaft by 540 to 1,000 rpm. The PV plant would normally serve several EVs, but in the present phase of the project a single prototype EV has been manufactured. The RAMseS EV can replace several agricultural ―I-category" ICE tractors up to 40 hp. The John Deere 3120 has been selected for comparison as it is a well known common tractor in agriculture (in this study this tractor will be referred to as ICEV). Some technical data of the John Deere 3120 are shown in Table 2.

Table 2. John Deere 3120 technical data [12].

Power (hp)	**Fuel Cons. (L/h) at 100% load**	**Fuel Tank (L)**	**Approximate Weight (kg)**	**Drive wheel**	**Fuel type**	**Battery (one)**	**3 Point-hitch**	**PTO (rpm)**	**Crankcase oil (L)**
29.5	7.18	51.03	1316	4	Diesel	12 V, 40 Ah	I-category	540	4.8

2.1. Environmental Life-Cycle Assessment (LCA)

The environmental life cycle assessment (LCA) takes into account the total environmental burdens associated with a system; from raw materials acquisition up to the end-of-life cycle. The LCA for RAMseS needs to take into account, in particular, the pollution generated by battery manufacturing and management, the EV, PV modules, frame and balance of system (BOS) which refers to module installation and support material.

The LCA calculation for the standard ICEV includes fuel production, fuel use, refueling, crankcase emission, evaporation emission, tractor construction and end of life dismantling. The release of thousand liters of burned oil, filters, noise and vibration are other kinds of pollutant and their impact on human and environment must be taken into account as well.

Several greenhouse gases are considered in the present analysis: CO_2, CH_4, SF_6, SF_4, C_2F_6, N_2O and PFC, are grouped together as CO_{2equ}. Other pollutants considered here are: heavy metals, SO_2, NO_x, CO, PM (particulate matter) and HC (hydrocarbons). NO_x is considered as composed of 90 to 95% of NO and 5% to 10% NO_2. All PM emissions are assumed to be smaller than 10 microns (PM_{10}) and 97% of the PM is considered to be smaller than 2.5 microns ($PM_{2.5}$) [13]. The calculations are based on the assumption that the RAMseS and the ICEV daily energy outputs are the same. The time frame of the calculation implies that the vehicles are produced in 2008.

Heavy metal, toxic gas, and GHG emissions are the main emissions from the commercial PV technologies, whereas liquid and solid wastes are for the most part being recycled and were not considered [14]. Life-cycle emissions factors for PV can be represented as life-cycle emission (in grams) divided by life-time net electrical output (kW_{el}) [15].

The (Well to Wheel) WTW emission factors for PV panels are shown in Table 3. We assume the use of monocrystalline silicon, taking data from different references which account for the whole lifecycle processe of the PV panels, from silicon feedstock production to cell and module manufacturing, using, transportation and disposal. In Table 3, the different values reported for CO_{2equ} emissions derive from different assumptions relative to the production methods for the modules and of the source of the energy that is used in the production process. In the table, ―case 1" refers to the current electricity mixture in Si production-Crystal Clear project and Ecoinvent database. Case 2 refers to the Union of the Co-ordination of Transmission of Electricity (UCTE) grid mixture and Ecoinvent database. It shows emissions corresponding to upstream electricity for the average grid mixture for continental Europe (UCTE). Finally, case 3 corresponds to the U.S. grid mixture and the Franklin database.

Table 3. m-Si PV life-cycle emission factors.

Solar cell technology	Emission (g/kWh_{el})			Test conditions	Ref.
	CO_{2equ}	SO_2	NOx		
m-Si (1997)	75	0.3 (sum of NO_x and SO_2)		-	[16]
m-Si (2010) (estimation)	30	0.1(sum of NO_x and SO_2)		-	[16]
Rooftop grid-connected m-Si (2004)	41	-	-	I = 1700, PR = 0.75, E = 13.7%	[17]
Roof top m-Si grid connected(2000)	60	-	-	I = 1700, L = 30yr	[11]
m-Si (2006)	35	-	-	I = 1700k, R = 0.75, L = 30yr, E = 14%	[11]
Ground-mounted m-Si (case 1) (2004–2006)	35	0.061	0.092	I = 1700, PR = 0.8, L = 30 yr, E = 14%	[14]
Ground-mounted m-Si (case 2) (2004–2006)	43	0.081	0.147	I = 1700, PR = 0.8, L = 30 yr, E = 14%	[14]
Ground-mounted m-Si (case 3) (2004–2006)	54	0.186	0.38	I = 1700, PR = 0.8, E = 14%, L = 30 yr	[14]
In-roof m-Si at present(2006)	35	-	-	I = 1700, PR = 0.75, E = 14%	[18]
In-roof m-Si at future	15.5	-	-	I = 1700 PR = 0.75, E = 19%	[18]
Rooftop m-Si	43	-	-	I = 1700	[19]

For the calculation of the emissions of ground mounted PV panels, it seems that case 2 is the one closest to the actual situation of the RAMseS project since the panels are manufactured in Europe. Also, if the average of the CO_{2equ} of Table 3, is used, we obtain a value that coincides with that for case 2.

In addition to gas emissions, PV panels are also associated with heavy metal emissions. According to [14], the life-cycle emission factor of atmospheric heavy-metals for m-Si panels are estimated as Table 4.

Table 4. m-Si PV heavy metal emissions.

Emission (g/GWh)	As	Cd	Cr	Pb	Hg	Ni
	2.3	1	6	9.8	1	26

These data are reported for each m-Si PV system by a ground-mounted BOS for an average insolation of 1700 $kWh/m^2/yr$, a performance ratio of 0.8, and lifetime of 30 years.

The specifications for the RAMseS batteries are reported in Table 1. For the lead batteries we show two estimates of the well to wheel (WTW) life-cycle assessment factors in Table 5. The batteries' life-cycle emission could be calculated using these factors in terms of the emissions per kg of battery net weight.

Table 5. RAMseS batteries' Life cycle Emission (g/kg of battery weight).

	CO_{2equ} (sum of items below)			SO_2	NOx	CO	Ref.
	CO_2	CH_4	N_2O				
Stationary	570	0.677	0.013	3.77	4.3	1.03	[20]
EV battery	970	-	-	6.8	6.3	-	[21]

The ICEVs environmental LCA is calculated using the rules of the United State's Environmental Protection Agency (EPA) [22]. According to these rules, the main emissions from non-road ICEVs result from (1) Exhaust and crankcase emissions; (2) Refueling emissions; (3) Evaporation emissions.

Diesel engines can approximately convert 20% of fuel energy to useful flywheel energy. If 2% of this energy is consumed for accessories, only 18% of fuel energy becomes as accessible flywheel energy [10]. On this point, ASABE [23] estimated the transmission losses of a typical tractor as an average of 83%. On the whole, the ICEV final fuel efficiency can be estimated as around 15%. So the ICEV must consume 222 kWh fuel everyday to produce 33 kW/day (as calculated earlier as the daily net consumed energy by the RAMseS EV). Considering that the energy density of diesel fuel is 13.76 kWh/kg, the ICEV will use 16.11 kg/day of fuel. The total fuel used over 30 years will be approximately 176 ton.

As illustrated in Table 2, the fuel consumption for the ICEV tractor at 100% load is 7.18 L/h, but the engine doesn't work at full load all the time. EPA [23] reports a load factor for diesel powered agricultural tractors in this power range equal to 0.59. Therefore, the fuel consumption at this load factor must be reduced to 4.24 L/h (3.6kg/h). So using 16.11 kg/day the ICEV can work 4.47 hours per day. The expected useful life of this ICEV is to be of 2,500 hours [13]. However, here we assume that the daily activity will depend on the energy input. Considering the calculated daily working hours, the tractor's useful age is about 1.5 years. Afterwards, the tractor must be replaced or undergo major repairs. If the tractor is overhauled four times, its life will be slightly over 7.5 years. Therefore, we can conclude that it must be replaced three times over the 30 years time. Because EVs have not as many moving parts as the ICEV, we can assume that it will need to be replaced only once.

On the subject of exhaust emissions, EPA [13] has proposed equations 1–5 that calculate emissions in ―zero-mile" and steady-state conditions, taking into account adjustments for transient operation, deterioration, and variations in fuel sulfur level. Brake specific fuel consumption (BSFC), measured in lb fuel/hp-hr, is a fuel rate measurement. In this approach, the emission factors for CO_2 and SO_2 are calculated on the basis of the BSFC value. The particulate matter (PM) calculation is done for PM_{10}. If $PM_{2.5}$ is taken into account, an adjustment of 0.97 is applied to the PM_{10} output.

Here are the relative equations:

$$EF_{adj}\,(HC, CO, NOx) = EF_{ss} \times TAF \times DF \tag{1}$$

$$EF_{adj}\,(PM) = EF_{ss} \times TAF \times DF - S_{PMadj} \tag{2}$$

$$EF_{adj}(BSFC) = EF_{ss} \times TAF \tag{3}$$

$$CO_2 = (BSFC \times 453.6 - HC) \times 0.87 \times (44/12) \tag{4}$$

$$SO_2 = (BSFC \times 453.6 \times (1 - soxcnv) - HC) \times 0.01 \times soxdsl \times 2 \tag{5}$$

In these equations, CO_2 and SO_2 are expressed in (g/hp-hr), HC is in adjusted hydrocarbon emissions in g/hp-hr. In Equation (2) S_{PMadj} is calculated using relation (6):

$$S_{PMadj} = BSFC \times 453.6 \times 7.0 \times soxcnv \times 0.01 \times (soxbas - soxdsl) \quad (6)$$

where 7.0 is a factor that accounts for the grams of PM sulfate per grams of PM sulfur. The *soxcnv* term represents the fraction of diesel fuel sulfur converted to PM. Usually this parameter is assumed to be equal to 0.02247 for non-road diesel vehicles. The *soxbas* is almost (3,300 ppm) 0.33 mass percent. Also for this case *soxdsl* is (500 ppm) 0.0500 mass percent. Substituting these parameters for S_{pmadj} in equation (6) yields 0.081 g/hp-hr. The flywheel energy at rated power that ICEV delivers in 30 years is 1231762 hp-hr, the S_{PM} at 30 year becomes 100 kg. For determining the flywheel energy, Ref. [10] demonstrated a 37.8% efficiency; of this value, 17.4% is related to standby working. Using Equations (4) and (5) respectively for CO_2 and SO_2 the results for 30 years are shown in Table 9.

The deterioration factor (DF) varies as a function of engine age. It is defined as:

$$DF = 1 + A \times (\text{Age Factor})^b \text{ for Age Factor} <= 1 \quad (7)$$

$$DF = 1 + A \text{ for Age Factor} > 1$$

where ~~-A~~" and ~~-b~~" are constants for a given pollutant/technology type. For ICE, ~~-b~~" is always equal to 1. This results in a linear deterioration pattern, in which the rate of deterioration is constant throughout the median life of an engine.

The age factor can be calculated as:

$$Age \quad factor = fraction \quad of \quad median \quad life \quad \exp ended = \frac{Cumulative \quad houre - load \quad factor}{median \quad life \quad at \quad full \quad load \quad in \quad hours} \quad (8)$$

EPA instructions for a 29.5 hp non-road engine in 2008 are based on a standard 4A Tier (according to the EPA draft NONROAD2004 which accounts for emission factors under four regulations that establish four tiers of emission standards (Tier1, Tier2, Tier3 and Tier4)). The emission parameters for this standard are shown in Table 6. To meet these standards limit value, it is anticipated that engines will have to be equipped with particulate filters and NO_x after treatments. The transient adjustment factors (TAF) are to be set as equal to 1 for Tier 4 engines [13].

Table 6. Emission parameters for 29.5 hp agricultural tractors (Tier 4A technology).

Emission parameters	BSFC	NOx	CO	PM	HC
Zero-Hour, Emission Factors-EFss (g/hp-hr)	-	4.7279	1.532 3	0.20	0.278 9
TAF	1	1	1	1	1
Deterioration Factor's coefficient (A) up to Tiers 3	-	0.008	0.151	0.473	0.027

For this type of technology, the BSFC is assumed 0.408 lb/hp-hr [13]. Since the dependence of the emission to deterioration is linear, for a more accurate computation the effects are calculated daily. Hence we integrate from the equations 1–3 during the life-cycle period. So, DF rewritten as:

$$DF = 1 + A.\frac{x}{1000\,hr} \quad 0 <= x <= 559 \tag{9}$$

where ―x" is a variable that counts days until (2500/4.47).

Because the EF factors declare to flywheel energy, to determining the sum of released emissions in 30 year, EFs in g/hp-hr multiplied by the daily flywheel energy ($\frac{1231762}{30 * 365} = 112$) and then integrated for the tractor life-time (559 day). Finally, we need to multiply it by a factor of 20 in order to take into account the number of tractor overhauling or replacement (30 years/1.5). Hence, rewriting Equations 1–3 we obtained:

$$HC = 20 \times 112 \int_0^{559} EF_{ss\ HC}.TAF_{HC}.(1 + A_{HC}.\frac{x}{1000}).dx \tag{10}$$

$$CO = 20 \times 112 \int_0^{559} EF_{ss\ CO}.TAF_{CO}.(1 + A_{CO}.\frac{x}{1000}).dx \tag{11}$$

$$NOx = 20 \times 112 \int_0^{559} EF_{ss\ NOx}.TAF_{NOx}.(1 + A_{NOx}.\frac{x}{1000}).dx \tag{12}$$

$$PM = 20 \times 112 \int_0^{559} EF_{ss\ PM}.TAF_{PM}.(1 + A_{PM}.\frac{x}{1000}).dx - S_{PMadj} \tag{13}$$

Because some unburned gases always pass through around the piston rings in diesel engines, the result is crankcase emission. EPA [13] assumes that crankcase HC emission factor is equal to 2% of the exhaust HC emission for all non-road engines. Then, 6.9 kg HC will be released to the atmosphere from the crankcase chamber in the considered period.

Table 7. Diesel fuel production emissions.

In g/GJ	CO2	NOx	CO	PM	HC
Feedstock production	1.692–3.4 (2.54)	7.98–9.5 (8.74)	1.395–5.1 (3.2475)	0	24.064–27.8 (25.93)
Feedstock transportation	0.6	15.04–20 (17.52)	0.376–1.7 (1.038)	0	0.93–26.1 (13.515)
Fuel production	3–6.96 (4.98)	4.9–8.04 (6.47)	0–0.798 (0.399)	0	10.03–57.036 (33.533)
Fuel distribution	0.2–0.7 (0.45)	1.504–10.6 (6.052)	0.4–0.7 (0.55)	0.1	0.303–1.079 (0.691)
Total	8.57	38.782	5.2345	0.1	73.669

Refueling emissions can be computed subdividing them in two sections: spillage and vaporization. In both cases, fuel ends up vaporized in the air as hydrocarbons. In terms of vaporization, every time that fuel is added to the vehicle tank, all the fuel vapor is replaced by fuel. The non-road 2004 report [13] considers a single emission factor of 0.0108 g/L for vapor displacement from diesel equipment under all conditions. Regarding spillage, it is derived from accidental losses or leaks. The Non-road2004 report considers a value of 3.6 grams of fuel spilled per refueling. Therefore if the ICEV tank volume is 51.03 L, the final value vaporized is 0.0813 g/L. If the total lifetime fuel consumption is 176 ton, almost 17 kg of HC are produced as the result of periodic refueling.

Although the tractor's tailpipe generates the most important emissions, the emissions from the other stages in the fuel chain cannot be ignored. Fuel production chains also have significant emissions. Table 7 shows emission rates during each of the four stages of the diesel fuel chains [24]. Considering that the consumed fuel at 30 year is 8743 GJ, the emissions due to fuel production are shown in Table 9.

For the evaluation of the pollution due to the vehicle manufacturing processes we need to consider the complete chain from the extraction and materials processing, all the way to the End-of-Life disposal. The impact of these parameters can be calculated taking into account the materials used for the construction material of the vehicles. Emission factors for some simple ICEV and EV are defined as a variable of vehicles unit curb weight [25]. The evaluated data are shown in Table 8. For ICEVs, it is not common to conduct a separate calculation for the battery, considering that the weight is very small. The curb weight of ICEV and EV (without battery) is 1,316 and 888 kg, respectively.

Table 8. RAMseS EV and ICEV construction emission for the considered period.

kg/kg of curb weight	CO_{2equ}	NO_x	**CO**	**PM**	**HC**
Extraction & Mat. Process	3.644	0.00506	0.012	0.00416	0.0011
Manufacturing	2.2453	0.0024	1.893×10^{-4}	5.966×10^{-4}	-
End-of-Life	0.0135	3.58×10^{-5}	1.77×10^{-6}	4.09×10^{-6}	-
Total	5.9	0.00749	0.012191	0.00476	0.0011

2.2. Environmental LCA Using SimaPro

To assess pollutants effects on the environment and on human health, the two systems (RAMSES and ICEV) were compared using the SimaPro software®. SimaPro is the most widely used life cycle assessment software used for assessing the environmental aspects associated with a product over its useful life.

The software has an already built-in simulation of an agricultural vehicle that we used without modifications. The software has also built-in routines for emissions from diesel fuel combustion. For the RAMseS system, three subassemblies were built, for the vehicle, the batteries and the PV system. For the batteries the fractional impact resulting from the materials used was derived from [21]. All the other parameters were the same derived for the analysis reported in the previous section. It is also assumed that at the end of the life of the system, all systems will be disassembled and the materials are recycled. There are more than 700 emissions in SimaPro results in which noise and vibration are also included. Although there are some differences between the calculated six major pollutants and software results, the results appear consistent.

2.3. Economics LCA

The monetary life-cycle cost (LCC) includes all costs necessary for installation, operation, maintenance and replacement during the useful life of the system, intended as formed of the vehicle and the PV charging and storage system. This value is usually computed as the sum of the initial, replacement, operation and maintenance costs.

The initial cost (C_{ini}) of the system is an important factor to investors especially those that are short in financial resources. According to the standard procedure, for PV projects this cost should be calculated as follows:

$$C_{ini} = C_{PV} + C_{SB} + C_{EVB} + C_{EV} + C_{BOS} + C_{PCU} + C_{L} - S_{EV} \quad (14)$$

C_{PV} is the purchase cost of the PV panels. C_{SB} and C_{EVB} are respectively the cost of stationary and EV battery. C_{EV} represents the cost of the vehicle, C_{BOS} is the cost of BOS, C_{PCU} is the cost of power conditioning unit (PCU), C_L is the land cost and S_{EV} is the salvage value of the EV at the end of its life. The PCU includes the costs for equipment such as inverter, cabling, rectifier, MPPT and battery charger. According to the literature [27,28] the civil works represent about 40% of the price of a PV plant and the engineering cost is almost 10 % of PV capital cost. In the present study, we'll assume that the RAMseS EV is mass produced in numbers comparable to standard ICEVs. Therefore, we'll neglect design and prototyping costs.

Operation and maintenance costs ($C_{O\&M}$) include; tax, insurance, recurring and maintenance costs. Some references [28] suggest that the operation and maintenance cost for PV, BOS and PCU to be zero; but this is an approximation and in the present study we'll make an effort to evaluate these costs. Usually, operation and maintenance costs for the first year ($C_{O\&M0}$) are assumed to be a fraction of purchase cost for PV, BOS and PCU [29].

$$C_{O\&M0} = m\,(C_{PV} + C_{BOS} + C_{PCU}) \quad (15)$$

where ―m" is a ratio between 0 and 1. For battery storage, the annual maintenance and salvage costs are considered to be zero [26].

When the discount rate (d) and the inflation rate (i) are the same, the $C_{O\&M}$ parameter can be defined by Equation 16-a, if this is not the case, Equation 16-b should be used [29].

$$C_{O\&M} = N \times C_{O\&M0} \text{ if } d = i \quad (16\text{-a})$$

$$C_{O\&M} = C_{O\&M0}\left(\frac{1+i}{d-i}\right)\left[1-\left(\frac{1+i}{1+d}\right)^{N}\right] \; if\; d \neq i \quad (16\text{-b})$$

where N is the life-cycle period in years. The discount rate is the factor that describes the changing value of money over time. It is equivalent to the amount of money that we could make with the capital if the money were invested in a bank. Cost escalation, also called inflation, is used to account for the fact that components and services normally get more expensive over time. In the present study, these factors have been applied to fuel, energy, maintenance costs and replacement parts. Traditionally, fuel costs are considered separately at a higher inflation rate [30]. These parameters are all subjected to strong uncertainties; therefore in the present study only one inflation rate will be assumed for all items.

The cost calculation for the EV is based on the data for existing vehicles. It includes the cost of tax, shelter and insurance (TSI) as, respectively, 1.5%, 0.7% and 0.25% of yearly custom cost [31]. For TSI calculation, custom costs are considered as the average over the life time. Therefore, the annual cost of TSI is 2.45% of the EV custom cost (C_{EV}). If the EV is replaced every L_{EV} years, then the TSI cost during the EV life-time (C_{TSI}) is given as (2.45% × L_{EV} × C_{EV}). This cost must be added to the EV purchase cost while the salvage cost (S_{EV}) is subtracted to it. We assume that the maintenance cost for the EV is zero, since it is very small in comparison to that of a conventional ICEV.

The replacement cost must be calculated as well in present value. Stationary and EV batteries, PCU and the whole EV are all parts that have to be replaced after some years. The replacement costs are given by Equation 17 [26].

$$C_R = C_{EVB}\left[\sum_{j=1}^{N_{EVBR}}\left(\frac{1+i}{1+d}\right)^{\frac{N.j}{N_{EVBR}}+1}\right] + C_{SB}\left[\sum_{j=1}^{N_{SBR}}\left(\frac{1+i}{1+d}\right)^{\frac{N.j}{N_{SBR}}+1}\right] + C_{PCU}\left[\sum_{j=1}^{N_{PCUR}}\left(\frac{1+i}{1+d}\right)^{\frac{N.j}{N_{PCUR}}+1}\right] +$$

$$C_{EV}(1+(0.0245\times L_{EV})-S_{EV})\left[\sum_{j=1}^{N_{EVR}}\left(\frac{1+i}{1+d}\right)^{\frac{N.j}{N_{EVR}}+1}\right] \tag{17}$$

In this equation N_{EVBR}, N_{SBR}, N_{PCUR} and N_{EVR} are the number of replacements, respectively, for EV batteries, stationary batteries, PCU and EV.

It is usual to install PV plants in barren and arid lands or on rooftops (for small projects): therefore we can consider the land cost as negligible. Hence, the LCC of the RAMseS project (LCC_{RAMseS}) in present monetary value can be shown as follows,

$$LCC_{RAMseS} = C_{ini} + C_R + C_{O\&M} \tag{18}$$

The LCC of the ICEV (LCC_{ICEV}) is divided in two recurring and non-recurring groups. The most important recurring cost is that of fuel. Non-recurring costs include the tractor initial purchase and its replacement. Although operation and maintenance (O&M), and TSI costs are considered as recurring costs, they are computed here as a percentage of the average initial cost during the life-time of the vehicle and therefore are added to non-recurring costs. As mentioned before for the case of the EV, the cost of TSI per year is almost 2.45% of the purchase cost.

ICEV maintenance includes considerable servicing, mainly to the engine. The main portion of maintenance costs is allocated to oils and filter changing, decarburizing and daily or weekly greasing. Research has shown that the cost of overhauling and maintenance for a 4WD ICEV is about 0.50% of its purchase price per 100 h operation, averaged over the vehicle's life-time [32]. The ICEV will have to be replaced after L_{ICEV} years and it is shown that it will work 1,630 h per year. Accordingly, the parameter that describes, operation and maintenance costs ($C_{O\&M}$) during the vehicle's life are given as:

$$C_{O\&M}\,in\quad ICEV\quad life = \frac{0.0050\times C_{ICEV}}{100\,hr}\times 1630\times L_{ICEV} = 0.08\times L_{ICEV}\times C_{ICEV} \tag{19}$$

C_{ICEV} is the purchase cost and L_{ICEV} is the useful life of the ICEV. The ICEV life-cycle cost due to replacement, TSI, and overhauling (non-recurring costs) ($C_{N\text{-}REC}$) are described by Equation 20. The equation can also take into account the salvage value (S_{ICEV}), subtracting it from the initial cost.

$$C_{N-REC} = C_{ICEV}(1 + (0.0245 \times L_{ICEV}) + (0.08 \times L_{ICEV}) - S_{ICEV})\left[\sum_{j=1}^{N_{RICEV}} \left(\frac{1+i}{1+d}\right)^{\frac{N.j}{N_{RICEV}}+1}\right] \tag{20}$$

Here, N_{RICEV} is the number of ICEVs that have to be replaced during the time scale of the calculation. The fuel cost (C_{Fuel}) is a recurring cost and it is given as:

$$C_{REC} = C_{fuel} = C_{yfuel}.\left\{\frac{1+i_f}{d-i_f}\left[1-\left(\frac{1+i_f}{1+d}\right)^N\right]\right\} \tag{21}$$

where C_{yfuel} is the yearly fuel cost and i_f is the inflation rate. The initial cost of ICEV can be estimated as:

$$C_{ini} = C_{ICEV} (1 + (0.0245 \times L_{ICEV}) + (0.08 \times L_{ICEV}) - S_{ICEV}) \tag{22}$$

Then, the total LCC_{ICEV} can be estimated as:

$$LCC_{ICEV} = C_{ini} + C_{REC} + C_{N\text{-}REC} \tag{23}$$

2.4. Comparison Indicators

The levelized cost of energy (LCE) is one of the commonly used indicators of financial performance in the evaluation of PV projects. It can be defined as the ratio of the total annualized cost of the project to the annual electricity delivered by the project. The method aims at converting the net cash-flow life-cycle costs into a series of annual payment of equal amounts. For a PV plant, the LCE is given by Equation 24 [26].

$$LCE = \frac{LCC.AF}{E_{year}} \tag{24}$$

where, E_{year} is the collected energy over a typical year and AF is the annuities factor that is given as:

$$AF = \frac{d.(1+d)^N}{(1+d)^N - 1} \tag{25}$$

The net present value (NPV) is another indicator that defines the differences between all cash inflows present values against the present value of all cash outflows associated with the investment project. The NPV is given as [32]:

$$NPV = E_{year}.C_E.\left\{\frac{1+i_e}{d-i_e}\left[1-\left(\frac{1+i_e}{1+d}\right)^N\right]\right\} - LCC \tag{26}$$

where C_E is the unit price of the electricity (in this case the worth of spent energy) and i_e is the inflation rate of electricity.

Another indicator that has great importance is the pay-back period (PBP). It is the length of time that it takes for an investor to recoup the investment. This index is of great importance to private owners or smaller firms that may be poor in cash. The PBP can be estimated as [32]:

$$PBP = \frac{initial \quad capital \quad \cos t}{Annual \quad benefit - annual \quad O\,\&\,M - annual \quad C_R} \tag{27}$$

3. Results and Discussion

The assessment of the RAMseS system is subdivided in two sections. In the first, we estimate the impact of emissions in monetary terms and in the second we carry out a detailed comparison of the RAMseS system and a conventional one in terms of an economic life cycle assessment. In both cases, we tried to include all the factors involved.

3.1. Monetary Effects of Environmental Emissions

Calculating the environmental effects of the two systems considered here, electric and conventional, we obtain the data shown in Table 9. Overall, the RAMseS project will release 57 ton of CO_{2equ} in the atmosphere during its life span of 30 years, and 46% of the total amount is due to the batteries. All the heavy metal emissions are due to the PV panels. Batteries and the EV might emit metals, but there are no data available for calculating actual values and we may assume these emissions to be small.

Table 9. Environmental emissions due to RAMseS and ICEV due to each step (kg).

Emissions (kg)	CO_{2equ}	SO_2	NOx	CO	PM	HC	As	Cd	Cr	Pb	Hg	Ni
RAMseS												
PV panels	20,748	39	71	-	-	-	1.1	0.5	2.9	4.7	0.5	12.5
Battery	25,926	178	178	34	-	-	-	-	-	-	-	-
EV Cons.	10,478	-	13	22	8	2	-	-	-	-	-	-
Total	57,152	217	262	56	8	2	1.1	0.5	2.9	4.7	0.5	12.5
ICEV												
Fuel Prod.	75	-	339	46	1	644	-	-	-	-	-	-
Fuel use	726,093	222	5824	1963	178	369	-	-	-	-	-	-
Vehicle Cons.	30,735	-	39	64	25	6	-	-	-	-	-	-
Total	756,900	222	6202	2073	204	1019	-	-	-	-	-	-

For the ICEV, fuel burning is the main cause of emissions while crankcase and refueling emissions are negligible. The ICEV will emit 757 tons of CO_{2equ} to the atmosphere during its assumed life of 30 years, 96% of which is generated at the tailpipe. This value corresponds to 24.2 tons of CO_{2equ} per year. The NO_x lifetime production is 6.2 ton, released as an effect of fuel combustion, fuel production and ICEV construction, by 94%, 5.4% and 0.6% respectively.

The environmental effect of a given system can be computed in monetary terms taking into account the external costs of each pollutants covered. For this calculation, the data are quantified in terms of the coefficients reported in Table 10. In this table, the external cost of pollutants is evaluated in Euro/ton from different references.

The differences in the data in the table are due to the different regions considered and to different assumptions. Monzon *et al.* [35] reviewed several studies for CO_{2equ} external costs. They found that the proposed values ranged from 8.5 to 66.5 Euro/ton and that the most commonly proposed ones are 19, 32.5, 46 Euro/ton; selecting 32.5 Euro/ton as a reasonable cost. For the costs of HCs, no data are available in the literature, so their effect could not be taken into account.

Table 10. ICEV and RAMseS monetary comparison.

	CO_{2equ}	SO_2	NOx	CO	PM	HC	As	Cd	Cr	Pb	Hg	Ni	Ref.
ICEV													
Euro/ton	-	2895	2020	0.7	87671	-	-	-	-	-	-	-	[34]
	29	2200	1500	-	22000	-	-	-	-	-	-	-	[7]
	18–48	9500	2000	-	-	-	-	-	-	-	-	-	[2]
	3–14	5000	4400	-	12000	-	-	-	-	-	-	-	[35]
Ave. (Euro/ton)	32.5	5000	2480	0.7	40557	-	-	-	-	-	-	-	
Cost (Euro)	24596	1110	15381	1.45	8273	-	-	-	-	-	-		
RAMseS													
Euro/ton	19	2939	2908	-	19539	-	8×10^4	39×10^3	31500	16×10^5	-	3800	[20]
Cost (Euro)	1086	638	756	-	164	-	88	19	88	7520	-	48	

The total ICEV environmental costs during its life-time, expressed in monetary terms, is almost 49,000 Euro. In comparison, the RAMseS environmental cost is much smaller: about 10,000 Euro. The main environmental cost of RAMseS is due to the use of lead in the batteries. The comparison of the two system's cost shows that the ICEV life-cycle environmental impact is 4.9 times larger than that of the RAMseS system. Also modeling this two systems in SimaPro illustrated almost 62% of RAMseS environmental effect is due to EVB, while 2% for EV and 36% for stationary installations.

3.2. Economical Life-Cycle Comparison between Two Systems

The value of some of the parameters and indicators that are used in this study is shown in Table 11. The custom cost of the ICEV (C_{ICEV}) is 11,250 € for 2008 [22]. We assume that the power conditioning unit (PCU) is replaced after 10 years that its replacement is twice over the 30 years lifetime of the tractor. We estimate that the depreciation of the tractor's custom price is 61% after 8 years and 73% after 15 years [31]. In this estimate, we consider also the effect of the inflation rate. The ICEV salvage cost after eight years can be estimated as 39% of C_{ICEV} and the EV salvage cost after 15 years can be estimated as 27% of C_{EV}. "d" for Lebanon is 12% in the reference year [40]. The escalation rate of all the items considered is assumed to be equal to the inflation rate reported in 2008 for Lebanon that is 5.6% [41]. However, in countries of the European Union, inflation ranges from about 5% to 12% and the discount rate from 1% to6%: these values will be assessed respectively for "d" and "i".

Table 11. The value of parameters used in this study.

Parameters	Values in This study	Similar references						
		[3]	[36]	[30]	[37]	[38]	[39]	[27]
Unit cost of PV panels (€/W_p), U_{PV}	3	-	-	3.2	2.2	2.3	4.8	2.6
Stationary battery unit cost (€/kWh), U_{SB}	182	-	-	80	54	-	81	96
Cost of BOS (% of C_{PV}), C_{BOS}	11	5-10	-	4	-	17–47	8	3.2
Unit cost of PCU (€/kW_p), U_{PCU}	700	-	-	590	-	515–955	920	964
PV life (year), N	30	-	20	20	30	20	25	25
PV O&M cost ratio (% of C_{PV}), m	1.2	2	1.3	2	3	3	1	1
Discount rate (%), d	5-12	10	10	7–15	8	10	5	4
Inflation rate (%), i	1-6	-	-	3–8	4	-	-	1.4
Stationary battery life (year), L_{SB}	15	-	-	-	5	7	7	5
Life of PCU (year), L_{PCU}	10	-	7	-	-	10	13	10
Inflation rate of fuel (%), i_f	5.6	0	5	5–10	-	-	-	1.4
Unit cost of EV battery (€/kWh), U_{EVB}	262	-	-	-	-	-	-	-
EV cost without battery (€), C_{EV}	15000	-	-	-	-	-	-	-
EV salvage cost (% of C_{EV}), S_{EV}	27	-	-	-	-	-	-	-
Tax-Shelter-Insurance (% of C_V), TSI	2.45	-	-	-	-	-	-	-
EV life (year), L_{EV}	15	-	-	-	-	-	-	-
EV battery life (year), L_{EVB}	2	-	-	-	-	-	-	-
Inflation rate of energy (%), i_e	5.6	-	-	-	-	-	-	-
ICEV life (year), L_{ICEV}	7.5	-	-	-	-	-	-	-
Custom cost of ICEV (€), C_{ICEV}	11250	-	-	-	-	-	-	-
ICEV O&M cost (% of C_{ICEV}), $C_{O\&MICEV}$	0.5/100 hr	-	-	-	-	-	-	-
ICEV salvage cost (% of C_{ICEV}), S_{ICEV}	39	-	-	-	-	-	-	-

The results for some economic indicators used in this evaluation are shown in Table 12.

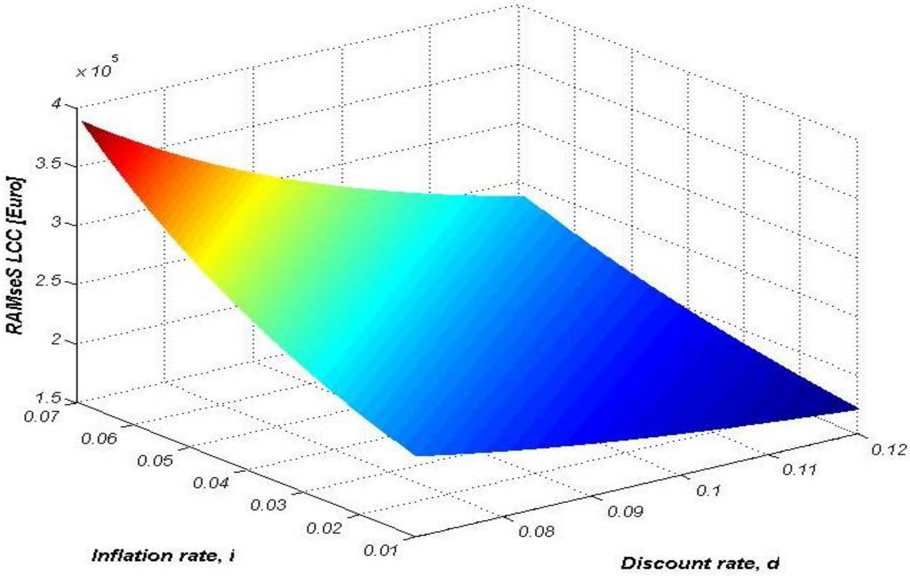
Table 12. Economic comparison parameters.

RAMseS	C_{ini} (€)	C_R (€)	$C_{O\&M}$ (€)	C_{ENV} (€)	LCC (€)	LCE (€/kWh)	NPV (€)	PBP (year)
Value	97518	SA	SA	10000	SA	SA	SA	SA
ICEV	C_{ini} (€)	C_{REC} (€)	$C_{N\text{-}REC}$ (€)	C_{ENV} (€)	LCC (€)	LCE (€/kWh]	NPV (€)	
Value	15682	SA	SA	49000	SA	SA	SA	

Of the total RAMseS initial cost (C_{ini}) almost 38% is allocated to the photovoltaic (PV) system, 17% for electric vehicle (EV), 16% for the stationary batteries (SB), 16% for the vehicle's batteries (EVB), 9% and 4% respectively for the power conditioning unit (PCU) and balance of system (BOS). The initial cost of the total RAMseS system is almost 6 times lager than that of the conventional ICEVs. The Replacement costs of the RAMseS system (C_R) is due to EVB, EV, PCU and SB respectively by about 90%, 2.5%, 5% and 2.5%. It is shown that the EVB initial and replacement costs are almost 52% of the RAMseS life cycle costs. Also SimaPro model shows almost 64% of RAMseS environmental cost is due to EV and EVB. This result confirms that for this kind of systems, the improvement of the batteries the first priority to make the system economically competitive.

In Figure 2 the LCC_{RAMseS} is shown as a function of inflation (i) and discount rate (d). "i" and "d" show a non-linear inverse dependency on LCC_{RAMseS}. Increasing "d" leads to a decrease in the LCC while increasing "i" increases the LCC. From the data of Figure 2 we can obtain the RAMseS LCC as a function of the values of "i" and "d" for different countries. For Lebanon, where the RAMseS prototype installed, we have i=0.056 and d=0.12 and the total calculated life cycle cost is almost 217,000 €.

Figure 2. RAMseS LCC versus different inflation and discount rates.



The total LCC of the conventional ICEV depends on the fuel price (price of fuel, Pf). Figure 3 shows how increasing Pf leads to a linear increase of LCC_{ICEV}. Increasing "d" decreases the slope, while increasing values of "i" (not shown in the figure) increase the slope. From a comparison of Figures 2 and 3 we can conclude that for Lebanon the LCC_{RAMseS} and LCC_{ICEV} will coincide if Pf becomes almost 1.45 €/L.

The net present value (NPV) is the sum of the net benefits in present value that the owner will obtain during the project life cycle. In other words, NPV is the differences between cash inflows and cash outflows. Since increasing the cost (worth) of consumed energy (C_E) increases the cash inflow, then C_E is the most important parameter that affects the NPV.

Figure 4 shows the RAMseS's NPV as a function of the discount rate and the value of the consumed energy. Here, the C_E variable is reported only for comparison as it depends on the revenues that the EV and ICEV bring to the farm in terms of agricultural work.

The RAMseS NPV becomes negative when the value of the of EV's consumed energy becomes less than 1.1 €/kWh. We see that changing of the "d" at zero NPV doesn't have any affect, while in positive NPV increasing of the "d" decrease the NPV.

Figure 3. ICEV LCC at different discount rates and versus fuel unit price.

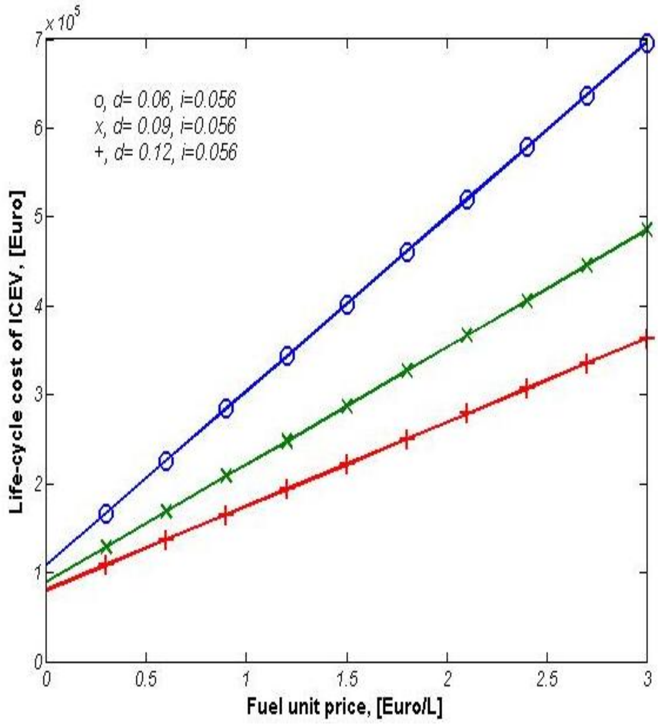


Figure 4. RAMseS NPV versus discount rate as a function of different costs of spent energy.

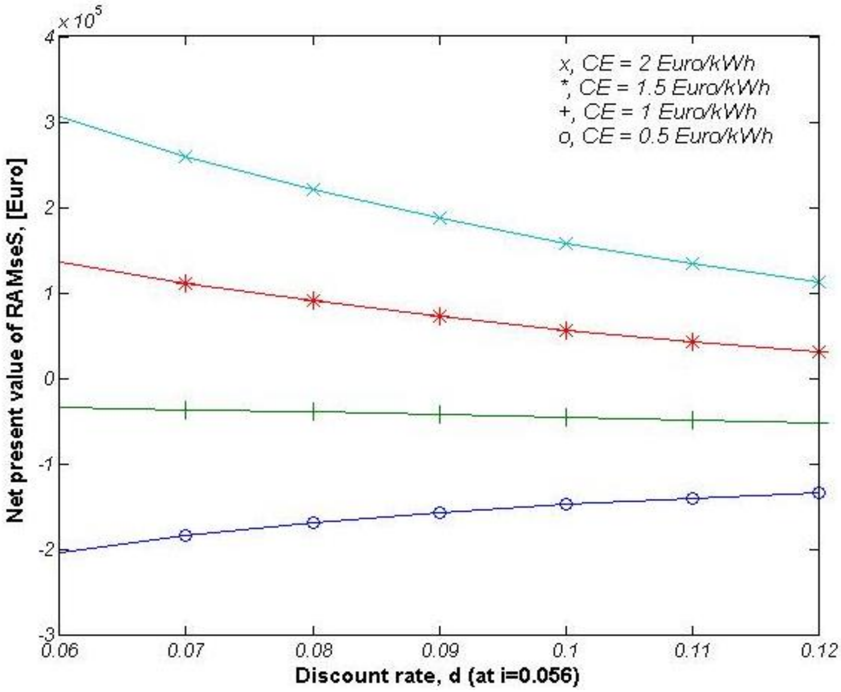
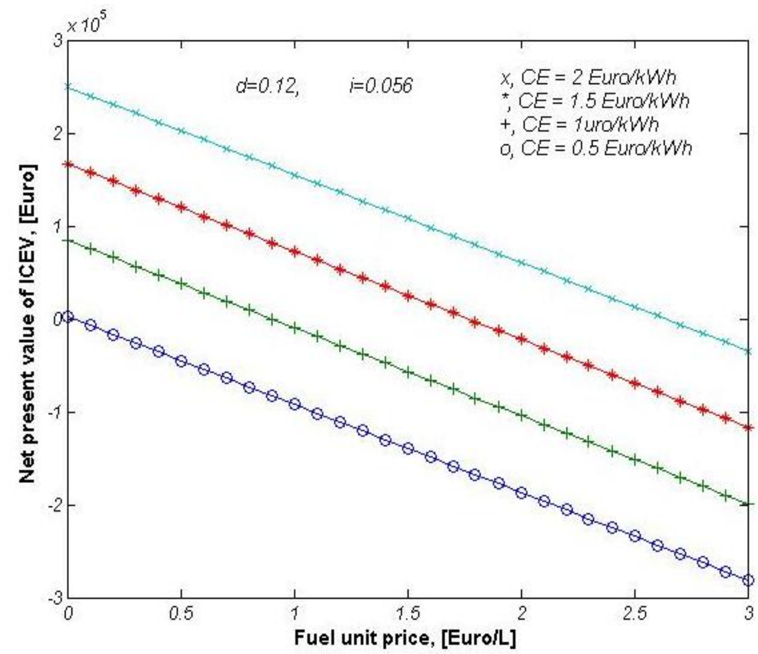


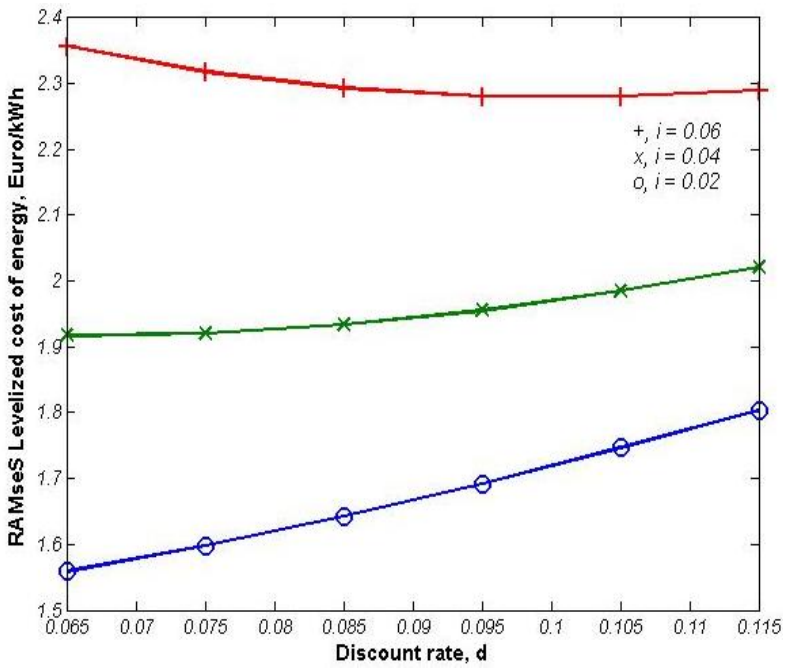
Figure 5 shows the NPV of the ICEV as a function of C_E and fuel unit price (pf) for the special condition that "d" is 0.12 and "i" is 0.056. When the C_E is 0.5 €/kWh and lower, the NPV of the ICEV becomes negative even in the hypothesis of zero fuel unit price. Considering a value of 1.1 €/kWh of C_E, as same as that of RAMseS C_E, the pf must be smaller than 1.2 €/L otherwise the NPV will be negative.

Figure 5. NPV of the ICEV versus discount rate in different costs of spent energy.



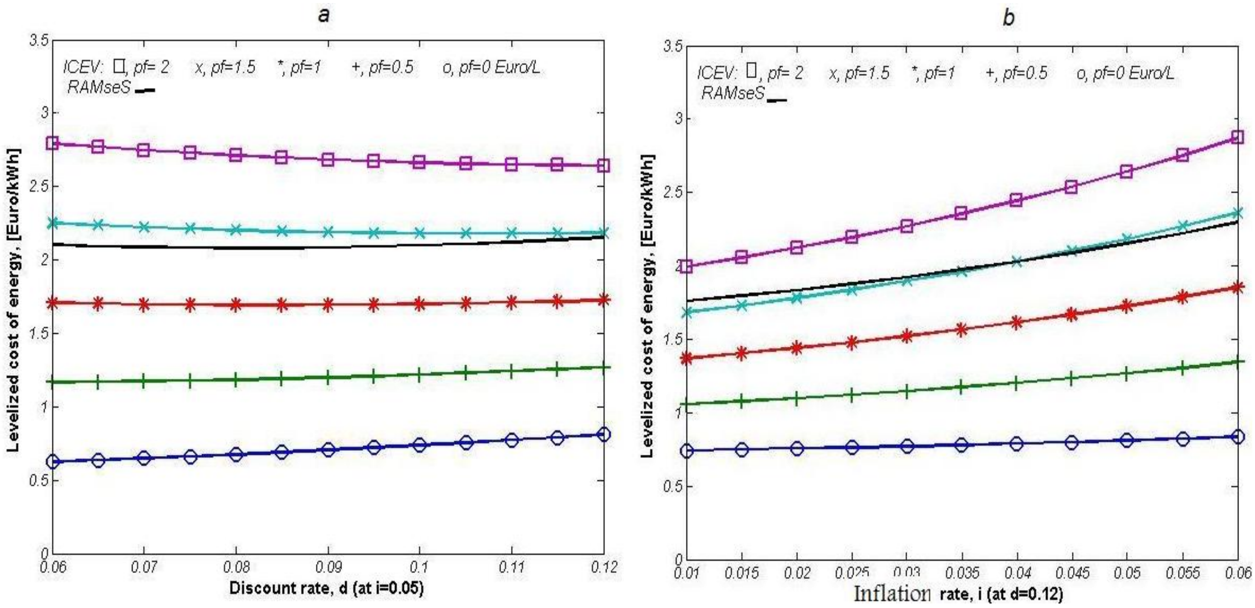
In general, the levelized cost of energy (LCE) (levelized cost of electricity) is defined as the unit price of the energy produced by PV systems. However, in the present study, the LCE indicator is referred to the unit price of the energy consumed by the vehicles, the RAMseS EV and the ICEV. This factor is the best indicator for a comparison of the two systems. Since it show the final consumed energy price in the present value. The RAMseS LCE is a function of “i” and “d”, as shown in Figure 6. The effect of the “i” parameter is larger than that of the “d” parameter, while the differences between maximum and minimum values of the LCE is 0.8 €/kWh. For Lebanon conditions the LCE of RAMseS is almost 2.2 €/kWh.

Figure 6. RAMseS levelized cost of energy as a function of discount rate.



In Figure 7 we show an evaluation of the LCE for the ICEV together with the same evaluation for the RAMseS system. Figure 7 (a) shows the LCE as a function of pf and ―d,” but for constant ―i”. In Figure 7 (b) ―i” is variable but ―d” is constant. We can see that the two parameters, ―d” and ―i”, have a small effect in comparison to pf. The most important result of this figure is that the LCE parity of the LCE ICEV and of RAMseS is obtained for a fuel price (pf) of about 1.45 €/L. So, in these conditions the RAMseS system is more convenient than a conventional ICEV based system.

Figure 7. (a) LCE of RAMseS and ICEV in different pf versus discount rate and **(b)** inflation rate.



The Payback time or period (PBP) is the time in years needed to the investor in order to recover the monetary investment. Obviously, investors will prefer short PBP. Figure 8 shows the RAMseS PBP versus different ―d” values and energy unit worth. The effect of the ―d” parameter is negligible but the worth of energy has a considerable effect on it. Higher energy costs will lead to shorter PBPs. In Figure 4 we show that the unit cost of energy for the RAMseS system must be more than 1.1 €/kWh, otherwise the NPV will be negative. Therefore, the RAMseS investor must recoup the investment at most in 12 years. But, if the energy unit cost were to be, for instance, 2 €/kWh, the PBP is less than four years.

As mentioned earlier, the largest portion of the RAMseS project cost is due to the batteries initial costs and their replacement. Therefore decreasing the cost of batteries unit price could led to remarkable decrease in the RAMSES life cycle costs. The same result could be obtained for system that require a lower investment in batteries; for instance fast charging systems based on supercapacitors. This solution, however, remains expensive at present.

Figure 8. RAMseS project payback period.

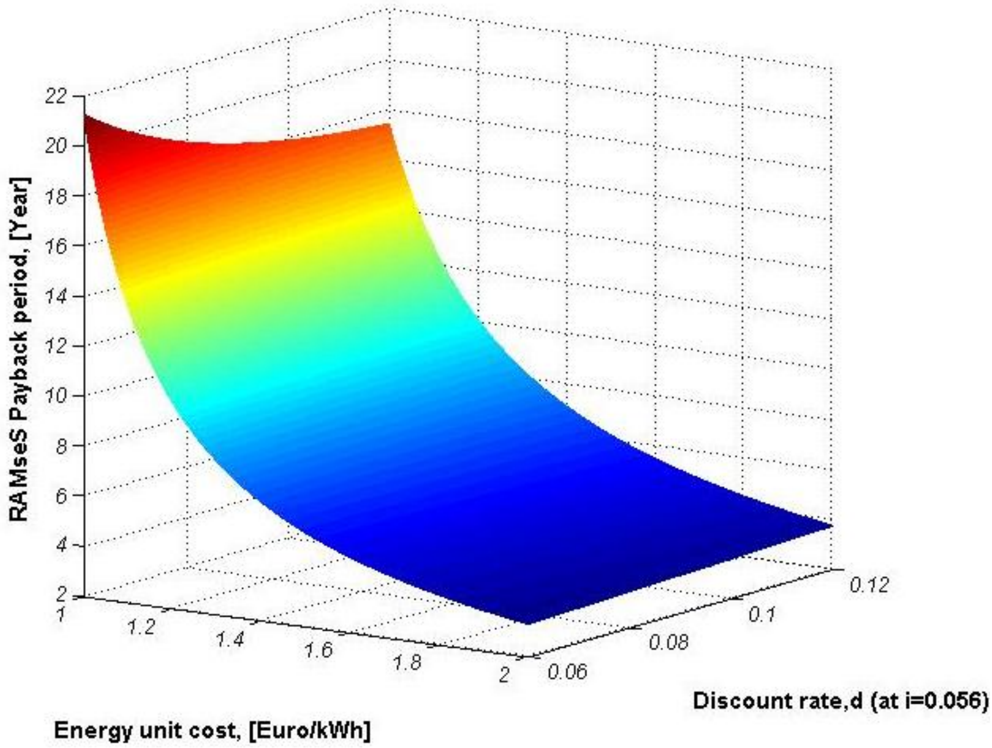


Figure 9. Fuel unit price versus decreases of battery unit cost.

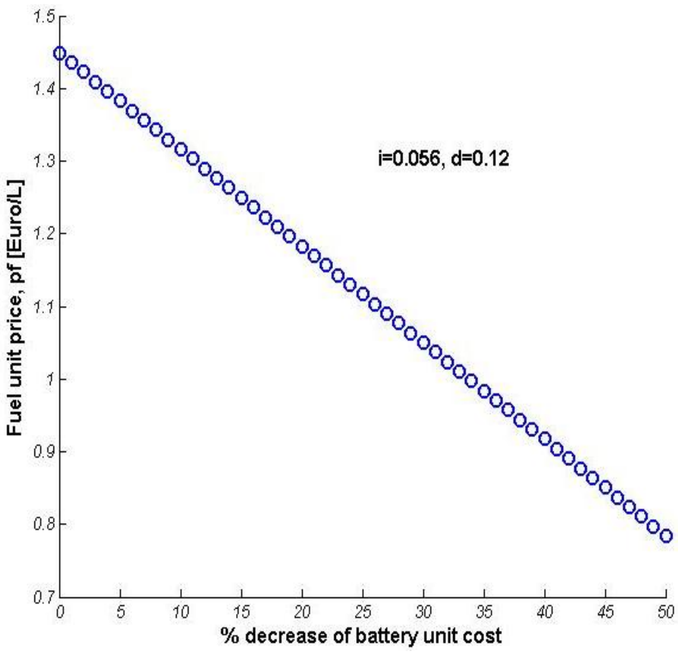


Figure 9 shows the effect of decreasing costs of batteries versus fuel price. It shows that if the batteries unit price decreases of 50% and reach values of 131 and 91 €/kWh respectively for EVB and

SB, then the RAMseS lice cycle cost will be the same of that of the ICEV at a fuel unit price as low as 0.8 €/L.

4. Conclusions

The RAMseS project's life-cycle costs, economical indicators and environmental effects have been evaluated and compared to those of a conventional internal combustion engine. The LCA for six airborne gases has been analyzed and converted to external costs. The results of the calculation show that a conventional vehicle (ICEV) will emit 757 ton of CO_{2equ} into the atmosphere in a life time of 30 years. The RAMseS system will emit only 57 tons of $CO2_{equ}$ during the same period. Translated into monetary terms, we can estimate that the external costs of the RAMSES system are about 10000 €, against 49,000 € for the ICEV.

Despite these advantages, the RAMSES system remains expensive in terms of initial cost (C_{ini}): about 6 times larger than that of a conventional $ICEV_i$. Therefore, government support remains necessary at the present stage for such system to take of in the market. Reducing these costs is not just a question of government support. We saw that the batteries of the electric vehicle count for almost 52% of the total life cycle costs (LCC_{RAMseS}). Modeling in SimaPro software concluded the EV and EVB batteries account for almost 64% of the RAMseS environmental cost. Therefore, batteries are a critical element of the RAMSES project and it is important to develop more efficient and less costly batteries.

In the end, the effectiveness of RAMseS project is mainly dependent on fossil fuel prices. At present, the collapse of the world markets have brought fuel prices down to values much lower than those of the market spike that brought them to near 150 dollars per barrel in July 2008. Oil prices remain highly volatile and it is difficult to forecast what will be their trends even in the near future. Therefore, the best assessment of the usefulness of the RAMseS project is not based on fuel costs but on fuel availability. It is known that, despite the vagaries of the price, it has not been possible to increase the world production of crude oil since 2004. This stasis in the word's production could be the start of the decline that is the mark of the concept of peak oil. In this situation of probable shortage of fuel in a not remote future, then the RAMseS concept offers a sustainable way out for mechanized agriculture and, in this sense, it will have been always a good investment.

Acknowledgments

The authors would like to acknowledge the European Commission for funding the RAMseS Project No. 32447 within the Sixth Framework Program (2002–2006).

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